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ABSTRACT

A battery of assessments to determine the potential contribution of tactual aids to the acoustic perception and speech identification of young deaf children was developed. The tasks were developed so that they could be implemented with standard audiometric equipment and applied to subjects of varying age and to different types of tactual aids. Illustrative results from four profoundly hearing-impaired children (aged 8 to 10 years) showed that tactual vocoders allowed detection of high frequencies that were not available to the subjects through aided audition. In most cases with these subjects, performance on simple detection and discrimination tasks showed facilitative effects with tactual vocoders. Facilitative effects were further evidenced in more complex phonemic identification tasks for all subjects. Tables, figures, and 11 references are provided. (DB)

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Assessment Techniques to Evaluate Tactual Aids for Young Hearing Impaired Children

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Abstract - To optimize the use of tactual aids for the deaf it is important to have a battery of assessments to determine the potential contribution of the aids to acoustic perception and speech identification. We have designed such a battery to be used with young hearing-impaired children. The tasks were developed so that they could be implemented with standard audiometric equipment and applied to subjects of varying age and to different types of tactual aids. Illustrative results from four profoundly hearing-impaired children showed that tactual vocoders allowed detection of high frequencies that were not available to the subjects through aided audition. In most cases with these subjects, performance on simple detection and discrimination tasks showed facilitative effects with tactual vocoders. Facilitative effects were further evidenced in more complex phonemic identification tasks for all subjects. The tasks can be used to determine possible benefits of tactual aids for individual hearing-impaired children.

INTRODUCTION

Hearing aids enhance the detection of sound in the frequency regions in which the user has residual hearing. The profoundly hearing-impaired have so little residual hearing that auditory aids cannot provide sufficient information to understand speech. Even with amplification, hearing is usually confined to the low frequency end of the speech spectrum with little or no perception or resolution of higher frequency information. One solution to the

problem of limited auditory reception is to augment the information available through the damaged sense of hearing with input from another sensory modality. Taction has often been the modality of choice, and a number of tactual speech aids have been developed over the past few years (1, 2, 3, 4).

Spectrally-oriented tactual vocoders have been shown to transmit extensive phonemic information (5, 6, 7, 8). Tactual vocoders divide the speech spectrum into channels based on frequency, and transmit the information in each channel to one of an array of stimulators worn on the skin. The user of a tactual vocoder learns to identify frequency information by noting the relative location of stimulation on the skin. Tactual vocoders operate in real-time with amplitude of stimulation at each stimulator proportional to the corresponding channel energy. Consequently the amplitude envelope of the acoustic signal and its temporal features are represented in substantial detail. Since a rich spectral code is presented, tactual vocoders provide acoustic information that is otherwise unavailable to the profoundly hearing-impaired.

Although tactual vocoders have been evaluated in research settings, only recently have they become commercially available for clinical usage. General guidelines of candidacy for tactual vocoder use have not yet been developed. As a rule, hearing-impaired children are evaluated extensively with and without their hearing aids, but little formal assessment is made of other sensory systems and their potential roles in acoustic perception. When tactual aids may play an integral role in rehabilitation of a particular child, it is important to evaluate tactual sensitivity and perception of

acoustic features through the tactual modality. We have devised a series of tasks to determine the extent to which taction can augment auditory perception in hearing-impaired children. The tasks were designed to be adaptable across a wide age range and a variety of tactual aids. Furthermore, the tasks were designed to be administered in a reasonable period of time with standard audiometric equipment. Four tasks ranging from simple detection to phoneme identification were examined.

EXPERIMENT 1: Tactual and Auditory Detection and Discrimination of Acoustic Frequency and Intensity

METHOD

Subjects

Four children, aged 8 to 10 years, participated in the study. All four were profoundly hearing impaired from infancy and had extensive experience with both auditory and tactual aids. Hearing aid amplification had been provided for each child upon identification of the hearing loss. In addition to regular hearing aid use, the children had used tactual aids for the four years prior to the study. For the first three years, they had used bench-top vibrotactile aids (9) 20 minutes/school day for speech therapy. In the fourth year, they used portable, miniaturized electrocutaneous devices (3) approximately 3 hours per day.

The children were enrolled in a model program utilizing tactual vocoders in speech training associated with a full-day elementary school program conducted as a collaborative effort of the University of Miami's Mailman Center for Child Development and the Dade County (FL) Public Schools. They had normal intelligence and were making good progress in their academic performance. Three of the children had no handicaps other than hearing impairment; one (Subject 4) exhibited moderate learning disabilities in addition to deafness. Information concerning each child's hearing status is presented in Table 1.

Equipment

Tactual Aid. The tactual aid used in the study was the

Tacticon 1600, a miniaturized electrotactile vocoder (3). The aid is designed to transmit information in the acoustic frequency range from 100 to 8000 Hz in 16 logarithmically-spaced channels. Constant current biphasic pulses are delivered to the skin of the abdomen through 16 concentric gold-plated electrodes. These electrodes (8 mm2) are mounted on an elasticized belt worn about the abdomen. Pulse width is 10 usec while pulse height is under user control within the range of 3 to 15 ma. Acoustic frequency is coded by spatial location, while acoustic intensity is coded by electrical frequency. The perceived dynamic range of stimuli presented through the device is estimated at 15-20 dB.

Each subject wore a small lapel microphone clipped to the upper left side of his/her clothing, about 3 inches from the shoulder. The processor box (weighing approximately one pound) was worn on the hip in a small pouch. The subject placed the belt on his/her moistened abdomen, engaged in a few minutes of warm-up (adjusting the pulse height to a comfortable level while speaking into the microphone), and indicated that he/she was ready. The subject was then asked to point to the area of the abdomen where stimulation was felt while the examiner, with face covered from the child's view, spoke the vowels /a/, /u/, and /i/ and the consonants /s/, / /, /m/ and /t/. If the subject accurately pointed to the areas of the electrodes known to be activated by the phonemes pronounced, it was assumed that the device was adjusted to the child's "comfortable feeling level", i.e., the gain was sufficient to convey information comfortably across the speech spectrum. A comparison of "comfortable feeling level" across test sessions revealed that each

subject adjusted the aid consistently to his/her habitual use level.

Auditory Aid. The auditory aid used in this study was the Telex Model TDR-4 auditory training unit which can operate in a traditional hearing aid or FM signal mode. Testing was done using the hearing aid mode only. The gain, frequency response and maximum output had been adjusted for each subject based on audiometric and classroom performance data. These aids had been worn by the subjects throughout the school day for the previous four years. The hearing aid was placed on the chest in a harness next to the microphone of the tactual aid. The aids, tactual and auditory, were checked for function by the experimenters prior to each test session.

Test Room and Test Signals

Testing took place in a double-walled acoustically-treated audiometric suite. The test signals were warbled pure-tones generated from a Grason Stadler 1701 audiometer located in the suite's control room and presented through a sound field speaker in the test room. Prior to each session, sound measurements were made at a point one meter from the speaker using a Bruel & Kjaer sound level meter Model 2203. Equipment was calibrated in decibels re sound pressure level.

The subject was seated at a small table facing the speaker. Care was taken that the microphone for each aid was located at the point of sound measurement. One examiner (E1), seated to the left and facing the child, provided instructions, demonstration and training for each experimental procedure. E1 also provided the subject with rewards for good performance. The rewards took the form of praise and colorful stickers that were popular with the

youngsters.

Test signals were selected and attenuated by a second examiner (E2) in the control room. To minimize bias, E2 followed a set protocol of stimulus presentation for each experimental procedure. E1 wore earphones which precluded accurate identification of the test signals. Both E1 and E2 judged the children's responses. Any disagreements between E1 and E2 were resolved by redoing the trial. Disagreement occurred on fewer than 1% of trials. It was often not possible to blind E2 to the test condition (tactual vs. auditory), since E1 used gestural cues related to hearing or feeling during the training sessions and subjects often responded in a like manner during the testing sessions.

Procedure 1a. Aided Auditory and Tactual Sensitivity Thresholds

Soundfield sensitivity thresholds were established for warbled pure-tones of 250 to 8000 Hz in separate sessions for each aid. The subject raised her/his hand for the duration of each signal detected. Thresholds were established according to standard audiometric procedure, beginning above presumed threshold, descending in 10 dB steps until no response was obtained and then ascending in 5 dB steps. Threshold was determined by a 2 out of 3 response criterion (and reported in dB SPL). In this way, aided audiograms and "tactograms" were plotted for each subject. To accommodate the youngsters' attention spans, the results were obtained over two or more test sessions, counterbalancing tactual and auditory conditions to account for the possibility of practice effects.

Procedure 1b. Aided Auditory and Tactual Frequency Discrimination

A same-different test paradigm was used to evaluate the subject's discrimination of acoustic frequency in each modality. The subject was asked to discriminate between a pair of warbled pure-tones presented in two consecutive intervals. Test pairs were chosen which differed by as much as two octaves and by as little as one-half octave. The pairs were 500 vs. 2000, 500 vs. 1000, 1000 vs. 2000, 4000 vs. 8000 Hz, and 4000 vs. 6000 Hz. Signals were presented at 80 dB SPL (well above threshold and yet still comfortable). If a subject's threshold was poorer than the level of the test signal in a given modality, that frequency was not presented and a CNT was entered in the appropriate data cell.

Prior to each test condition, the procedure was explained orally and in sign language. Training trials were provided until the subject demonstrated that he/she understood the procedure and then test trials were begun. During training E1 provided feedback as to whether the subject's responses were correct or incorrect. For the test trials, no feedback was provided, but the subject was praised for each trial regardless of the outcome.

E1 signaled to the subject to attend (listen or feel) prior to the initiation of each trial. E1 raised one finger to indicate interval 1 and two fingers for interval 2. The subject responded by saying "same" if he/she thought the signals in the two intervals were the same and "different" if they were perceived as different.

A trial consisted of two 2-sec signals separated by approximately 2 sec of silence. Trials were administered in blocks of four. If a subject failed to achieve 75% correct on two blocks

of trials, an additional block was administered. If the subject failed to reach criterion after three blocks, testing was discontinued and repeated on another day. In most instances, subjects failing on a first test failed on the second test as well. If the child passed the second test, a third session was run to confirm the results. Trial type was randomized within blocks with each block containing two same trials (high-high and low-low) and two different trials (high-low and low-high).

Signals were also presented at 25 dB Sensation Level (re threshold for the frequency under test) for two subjects to assure that discrimination was due to pitch and not loudness cues.

Procedure 1c. Aided Auditory and Tactual Intensity Discrimination

A same-different test paradigm was used to evaluate subjects' discrimination of acoustic intensity in each modality. Each subject was asked to discriminate between the intensity of a pair of 500 Hz warbled tones presented in two consecutive intervals. Test pairs were chosen which differed by 15 decibels (90 vs. 75), 10 decibels (85 vs. 75) and 5 decibels (85 vs. 80). In order to provide a comparison of tactual intensity discrimination with the best auditory discrimination possible for the deaf children, testing was initially limited to 500 Hz, the frequency at which the hearing-impaired subjects showed maximum auditory dynamic range.

As in Procedure 1b, instructions and a training period preceded the test trials. E1 signaled to the subject to attend (listen or feel) prior to the initiation of each trial, then raised one finger to indicate interval 1, and two fingers for interval 2. The subject

responded by saying "same" if he/she thought the signals in the two intervals were the same intensity and "different" if the signals were perceived as different.

A trial consisted of two 2-sec tones separated by approximately 2 sec of silence. The same trial block and testing sequence was followed as in Procedure 1b. Trial type was randomized within blocks with each block containing two same trials (one pair with the lower intensity, the other with the higher) and two different trials (one pair with the lower intensity signal occurring first and one pair beginning with the higher intensity signal).

To determine if the results were dependent upon frequency, two subjects were also tested for the three intensity differences using a 1000 Hz warbled-tone signal.

RESULTS

Sensitivity Thresholds

Tactograms and aided audiograms for each child are displayed in Figure 1. The aided audiograms are typical of those for the profoundly hearing-impaired with responses below 1000 Hz and occasional responses at higher frequencies. Subject 2 showed no responses at higher frequencies. Subject 1 was the only one to respond at 4000 Hz.

Each subject could tactually detect all pure tones. Threshold responses varied by 15 dB, from 40 to 55 dB SPL. Tactogram patterns tended to be "flat", varying little with frequency, as expected since each electrode transmits the same number of electrical pulses if provided equal channel input.

The data presented in Figure 1 clearly demonstrate that tactual detection of acoustic information across the spectrum needed for speech is possible. These results are comparable to aided audiograms of patients with cochlear implants (10). Whether the frequency or location of the signals can be distinguished from one another, or their presence merely detected, cannot be determined using detection paradigms. Thus, the frequency and intensity tasks were used to test the ability of the children to discriminate among signals in important acoustic domains.

Frequency Discrimination

Each child's score on each frequency comparison for both tactual and auditory conditions is presented in Table 2. The auditory tests were conducted only for those signals that were audible. Pluses indicate greater than 75% correct and minuses less than 75% correct. In every instance, when the subject's auditory threshold allowed testing at the specified frequencies, discrimination was demonstrated. Generally, discrimination was obtained for tactual conditions as well. However, despite numerous training trials repeated over two test sessions, Subject 1 could not discriminate signals above 1000 Hz that differed by an octave or less. None of the subjects could differentiate the 4000 and 6000 Hz signals. Subjects 3 and 4 performed accurately on the frequency discrimination task when signal sensation level was taken into account indicating that discrimination was based on information in the frequency, rather than the intensity, domain.

Intensity Discrimination

The results of the intensity discrimination testing are displayed in Table 3. The 75% cutoff criterion used for frequency discrimination was also used in the intensity discrimination task. Results on the intensity discrimination task differed significantly from subject to subject. Subject 4 performed well on both auditory and tactual conditions; Subjects 2 and 3 performed poorly auditorily but were successful at tactual intensity discrimination. Despite repeated training, Subject 1 could not discriminate the intensity differences in either modality. Discrimination of the 5 dB difference was clearly more difficult than discrimination of the 10 and 15 dB differences. Subjects who succeeded at 5 dB typically achieved scores near 75% correct, while for 10 and 15 dB differences, their scores were 100%. The performance of Subjects 3 and 4 with a 1000 Hz test signal was similar to their performance with the 500 Hz signal, with the exception that Subject 4 failed to reach criterion for the 5 dB difference with 1000 Hz in the auditory modality.

EXPERIMENT 2: Aided Auditory, Tactual and Visual Phoneme Identification

While determinations of threshold and frequency and intensity discrimination are important factors to consider when evaluating a sensory aid for speech perception, it is not clear how these dimensions relate to speech discrimination. Threshold sensitivity requires detection; discrimination tasks require same-different

judgements; perceiving speech through a tactual vocoder is a pattern perception or identification task. Perception of speech is clearly more complex than the detection of variations in frequency and intensity or the mere detection of a signal. In order to provide a better perspective on the ability of tactual vocoders to provide specific phonemic information to young children, a phoneme identification task was employed.

Subjects

The same four profoundly hearing-impaired children participated in Experiment 2.

Procedures and Materials

The subjects were tested in a sound-treated booth with two experimenters present. The subject faced E1 across a table, at a distance of about 5 feet. E2 was seated about 5 feet to the subject's right. E1 administered all test stimuli with live voice and was blind to the aid or aids used during each condition with the exception of whether or not lipreading was available. For this experiment, the Telex aids were used in the FM mode only. Six conditions were tested: Hearing Aid only (H), Lips only (L), Hearing Aid Plus Lips (H+L), Vocoder only (V), Vocoder Plus Lips (V+L), and Vocoder Plus Hearing Aid Plus Lips (V+H+L). Using this approach, it was possible to assess independently the contribution of each sensory modality and to assess synergism between modalities as well. For conditions without lipreading , E1 covered her entire face with a large opaque screen.

Four words which are difficult to lipread were chosen to

minimize the possibility of ceiling effects in the visual modality: they were "sue" /su/, "to" /tu/, "do" /du/ and "new" /nu/. In addition, these words were chosen because they differ by only a single phoneme and, therefore, cannot be identified on the basis of syllable number. The words represent differences in manner of initial consonant production and in voicing characteristics. These features are often difficult for hearing-impaired listeners to identify. The four words were used in three tests of discrimination, a 2-choice, 3-choice and a 4-choice task. For the 2-choice task, four word-combination pairs were used: /su/-/nu/, /tu/-/du/, /su/-/du/ and /tu/-/nu/. For the 3-choice task all four possible 3-way combinations were tested. For the 2-choice task, each member of each pair was tested 10 times for a total of 20 trials per pair. For the 3-choice task, each member of each triplet was tested six times (18 trials/triplet) and for the 4-choice task, each member of each quadruplet was tested five times (20 trials/quadruplet).

At the beginning of each session, 5X7 cards with the test words written in English orthography were placed on the table in front of the subject. Each of the words was pronounced several times giving the subject an opportunity to feel, see and listen to each stimulus. The subject could request repetitions until he/she was confident that the stimulus word was familiar. Following familiarization, the experimental trials were begun. E1 pronounced a single word, and the subject was required to respond by pointing to the correct card from an array of 2, 3 or 4 cards. Feedback with correction was provided on each trial. E2 recorded all responses and randomly

selected all trials and test word combinations for E1. In addition, E2 randomized conditions at the beginning of each session and turned on and off the appropriate aid. E1 was blind to conditions except those involving lipreading. In conditions involving lipreading, E1 was unaware of which, if any, aids were being used.

After testing was begun, it became apparent that Subjects 3 and 4 performed near 100% accuracy for most conditions on the 2-choice task. Therefore, they were tested only in 3- and 4-choice formats where differences between modalities were obtained. Subjects 1 and 2 performed the 2-choice tasks and then immediately proceeded to the 4-choice format. While it would have been ideal to test subjects 1 and 2 in the 3-choice task as well, the ending of the school year precluded extensive testing.

RESULTS

Results of the 2-choice test are presented in Figure 2a for Subject 1 and in Figure 2b for Subject 2. Chance performance on this task is 50%. Subject 1 had a mean percent correct of 59% for H, L and H+L conditions while Subject 2 exhibited a mean performance of 64% in these conditions. For conditions V and V+L, Subject 1 obtained a mean performance of 88% correct and Subject 2 obtained 90% correct. Both Subject 1 and Subject 2 obtained their highest mean scores for Vocoder alone, though the difference among Vocoder conditions was small. If single modalities are examined for both subjects, it is apparent that tactual performance is greater than performance in either the visual or auditory modality.

Results of the 3-choice task are presented in Figure 3a for

Subject 3 and in Figure 3b for Subject 4. Chance performance on this task is 33%. Subject 3 showed a mean performance of 56% correct on H, L and H+L conditions and 87% correct on V and V+L conditions. Performance on V was much better than performance on H or L conditions. Subject 4 showed a smaller difference in performance across conditions involving V vs. conditions without V than did the other subjects. Mean performance on conditions without vocoder was 63% correct while the V and V+L conditions showed mean performance of 83%; only the H condition differed markedly from all other conditions. Examination of each of the conditions shows that the discrepancy between Vocoder and non-Vocoder conditions for Subject 4 is attributable to this poor performance in the H condition.

Four-choice results for all subjects are presented in Figure 4. When the results are compared across single modalities for all subjects (V, L and H), it is clear that, again, the tactual (70%) is superior to either the auditory (37%) or visual (49%) modality. If combined modalities are considered, H+L yields 56% correct performance while V+L yields 89% correct. Subject 1 shows poorer performance in combined (V+H+L) than in the V+L condition. Performance declined when hearing was combined with vocoder and lips.

SUMMARY AND DISCUSSION

The present work describes a simple battery of assessments to determine the potential benefit of tactual aids for individual

hearing impaired children. The tasks are easily applied, and require only standard audiometric equipment. To illustrate the use of the assessment techniques, the assessments were conducted with four profoundly hearing-impaired children who have had experience using tactual vocoders in a classroom setting over an extended period of time. Since a variety of investigators have reported gains in tactual speech perception only after extended experience with the tactual device (5, 6, 7, 9, 11), it is important to recognize that these results may have been quite different without extended subject experience. Measures of tactual and auditory sensitivity and discrimination of frequency and intensity were obtained and compared across the subjects. In addition, phoneme identification in three modalities (taction, audition and vision) was studied so that the efficacy of the aids for transmitting phonemic information could be assessed and compared.

Of the four tasks administered to these four subjects, the simple threshold detection task yielded the least intersubject variability in both modalities. Subjects consistently indicated tactual thresholds between 40 and 55 dB SPL regardless of test frequency. Aided auditory thresholds showed patterns typical of profound hearing loss. Despite similarities in thresholds of detection, subjects differed substantially in their ability to perform the more complex discrimination tasks.

Performance on phoneme discrimination tasks was marked by variability. The nature of the variability is most easily examined on the 2-choice task. For example, the poorest auditory performance was generally found on the /tu/-/du/ and /tu/-/nu/ contrasts. /Su/-/nu/ was more easily discriminated, a finding unexpected in view of

the severity of the hearing losses in the subjects. The children probably used strategies different from those used by normal listeners to detect the phoneme differences, attending to more global features of the stimuli. For the /su/-/nu/ contrast, they may well have compared the presence of the noise burst of /n/ with the absence of the burst of /s/ which was probably imperceptable to them. Likewise, the formant transitions of the /tu/ and /du/ were likely to be too rapid for the hearing-impaired subjects to distinguish any differences. In addition, some variability must also be attributed to that normally seen in the performance of children, particularly on tasks requiring strict attention. Differences in performance across contrasts is not the concern of this analysis but rather general patterns of performance across modalities.

Subject 1 presented the least interpretable pattern of responses. Auditory detection was demonstrated up to 4000 Hz, and frequency discrimination in the auditory modality was good for frequencies that could be tested. However, tactual performance was poorer than that of any other subject and frequency discrimination was restricted to the low end of the frequency range where frequency resolution is highest due to the logarithmic spacing of channels in the Tacticon device. Subject 1 differed from other subjects in intensity discrimination as well, showing no discrimination in either modality at any intensity difference. Despite the fact that this pattern of results would not seem to indicate much benefit from the tactual device, Subject 1 showed a clear benefit from the vocoder in the phoneme identification task. Conditions with Vocoder

(V and V+L) yielded more accurate discrimination than conditions without Vocoder (H, L and H+L). Subject 1 showed a decrement in performance in V+H+L conditions (relative to the V+L condition) indicating that sensory integration was not occurring when auditory input was combined with tactual and visual information. Combining visual and tactual modalities, however, was facilitative. In general, Subject 1's performance was marked by variability, and the pattern of results was atypical of other subjects tested.

Subjects 2 and 3 showed similar patterns of performance on the discrimination tasks. Neither subject was able to discriminate any intensity difference auditorily, but both were able to discriminate all intensity differences tactually. Frequency discrimination was also similar with the exception that Subject 3 could be tested auditorily across a broader frequency range than Subject 2. Both subjects could discriminate the one- and two-octave intervals tested. Given the superior tactual performance in detection, frequency discrimination and intensity discrimination, it is not surprising that these subjects also showed superior phonemic discrimination performance in Vocoder conditions. Their scores on all the Vocoder conditions (V, V+L, and V+H+L) exceeded those of non-Vocoder conditions (H, L, and H+L).

Subject 4 showed the least discrepancy between tactual and auditory performance across the tasks of Experiment 1. Tactual performance exceeded aided auditory performance only with respect to the detection of high frequency signals. Likewise, the discrepancy between Vocoder and non-Vocoder conditions was relatively small for the 3-choice phoneme task. Hearing (H) was clearly worse than any other condition but combining Lips with Hearing (H+L) brought

performance to the same level as Vocoder conditions. Results from the more difficult 4-choice task do, however, show substantial positive effects of tactual input. Perfect performance was obtained from both V+L and V+H+L conditions while the mean for H, H+L and L conditions was 58%.

Despite variable patterns of performance across subjects, it is clear that for all subjects phoneme discrimination was enhanced when the tactual aid was used. For two of the subjects (1 and 4), evidence of the usefulness of the tactual aid was not demonstrated in simple detection and discrimination tasks but became obvious when complex speech signals were used in a phoneme identification task. Subjects 1's ability to identify phonemes tactually is particularly surprising given the negative results of the simpler detection and discrimination tasks.

Evaluation of children's use of auditory and tactual aids provides information not only about each child but also about the aids utilized. In the present study, it became obvious that the Tacticon 1600 failed to provide for the discrimination of a 1/2 octave interval (4000 - 6000 Hz) toward the high end of the frequency range of the device. In addition, intensity discrimination with less than 10 dB differences proved difficult.

In summary, a variety of detection and discrimination tasks were administered to four profoundly hearing-impaired children. The tasks were designed to be easy to administer and to use simple audiometric equipment. Results indicate that facilitative effects of a tactual aid may be evidenced in different tasks for different children but that all the profoundly deaf children studied here

evidenced superior phoneme identification (on the limited set studied) with the tactual aid. Continued exploration of evaluation procedures for tactual aids seems warranted.

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FIGURE CAPTIONS

Figure 1. Tactograms and Aided Audiograms for four subjects

Figure 2a and 2b. Two-choice identification of phonemes for Subjects 1 and 2. (Hearing-H, Lipreading-L, Vocoder-V)

Figure 3a and 3b. Three-choice identification of phonemes for Subjects 3 and 4.

Figure 4. Four-choice identification of phonemes for all subjects

TABLE 1

Subject Demographics

Subject # and Age at time of study	Pure Tone Average for better ear	Etiology	Age of Identification	Age Aided	Other Disabilities
1 8-11	97 dBHL	Unknown	8 mo.	10 mo.	None
2 8-5	95 dBHL (2 frequency NR at 2k)	Genetic	8 mo.	10 mo.	None
3 10-0	100 dBHL	Genetic (Probable)	1 yr 9 mo.	2 yr.	None
4 9-11	102 dBHL	Unknown	2 yr.	3 yr.	Mild LD

TABLE 1

TACTUAL & AUDITORY (AIDED) FREQUENCY DISCRIMINATION @ 80 dB SPL

	SUBJECT							
	1		2		3		4	
FREQUENCY	Tac	Aud	Tac	Aud	Tac	Aud	Tac	Aud
500 Hz - 2 KHz	+	+	+	CNT	+*	+*	+*	+*
500 Hz - 1 KHz	+	+	+	+	+	+	+	+
1 KHz - 2 KHz	–	+	+	CNT	+	+*	+	+
4 KHz - 8 KHz	–	CNT	+	CNT	+	CNT	+	CNT
4 KHz - 8 KHz	–	CNT	–	CNT	–	CNT	–	CNT

+ = GREATER THAN 75%
– = LESS THAN 75%
* = ALSO TESTED AT 25 dB SL WITH THE SAME RESULTS
CNT = COULD NOT TEST - NO MEASUREABLE HEARING AT ONE OR BOTH FREQUENCIES

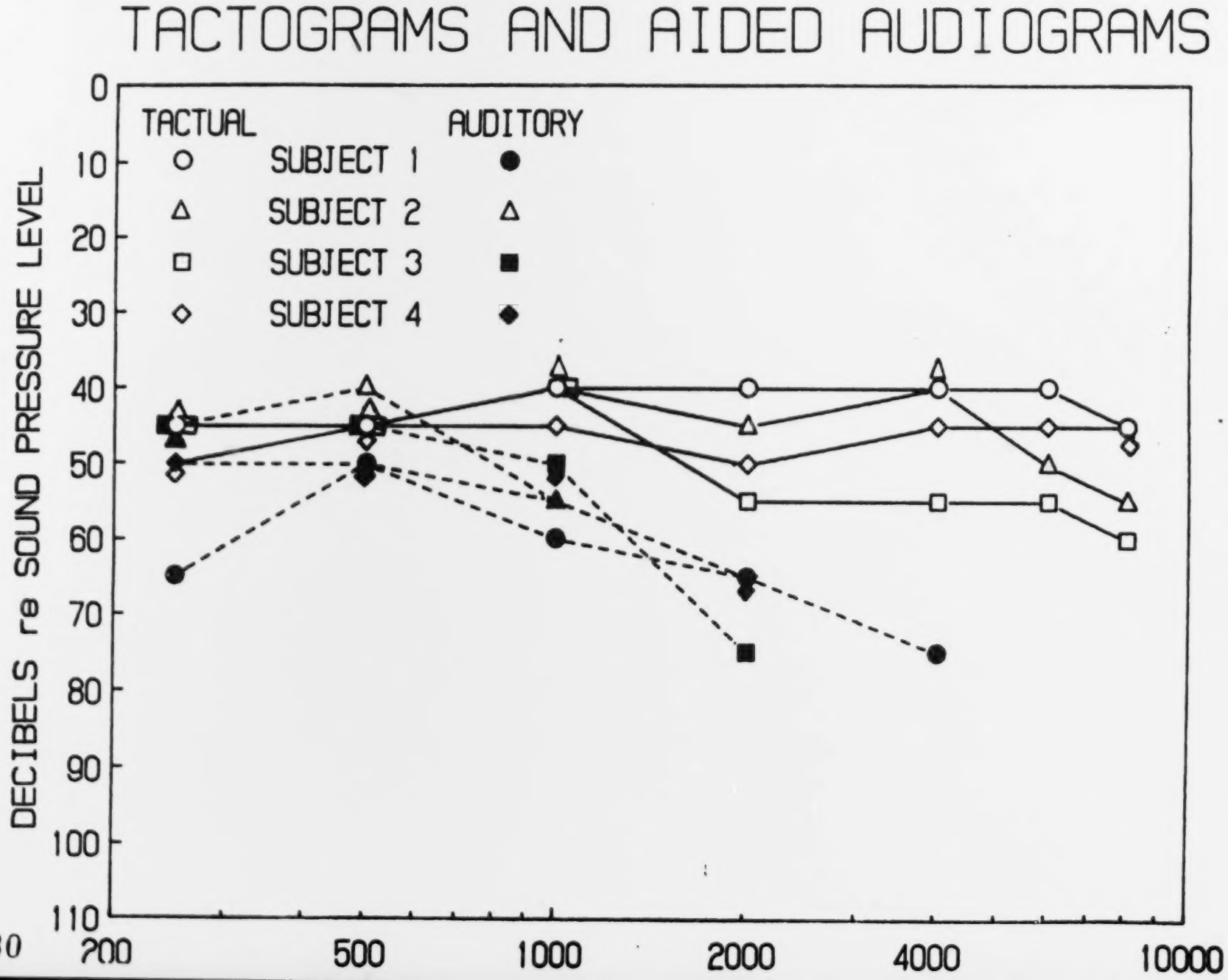
TABLE 2

TACTUAL & AUDITORY (AIDED INTENSITY DISCRIMINATION @ 500 Hz

	SUBJECT							
	1		2		3		4	
DIFFERENCE	Tac	Aud	Tac	Aud	Tac	Aud	Tac	Aud
15 dB	–	–	+	–	+	–	+	+
10 dB	–	–	+	–	+	–	+	+
5 dB	–	–	+	–	+	–	–	+

+ = GREATER THAN 75% – = LESS THAN 75%

FIGURE 1


TACTOGRAMS AND AIDED AUDIOGRAMS
TACTUAL
AUDITORY
SUBJECT 1
SUBJECT 2
SUBJECT 3
SUBJECT 4
DECIBELS re SOUND PRESSURE LEVEL
0
10
20
30
40
50
60
70
80
90
100
110
200
500
1000
2000
4000
10000

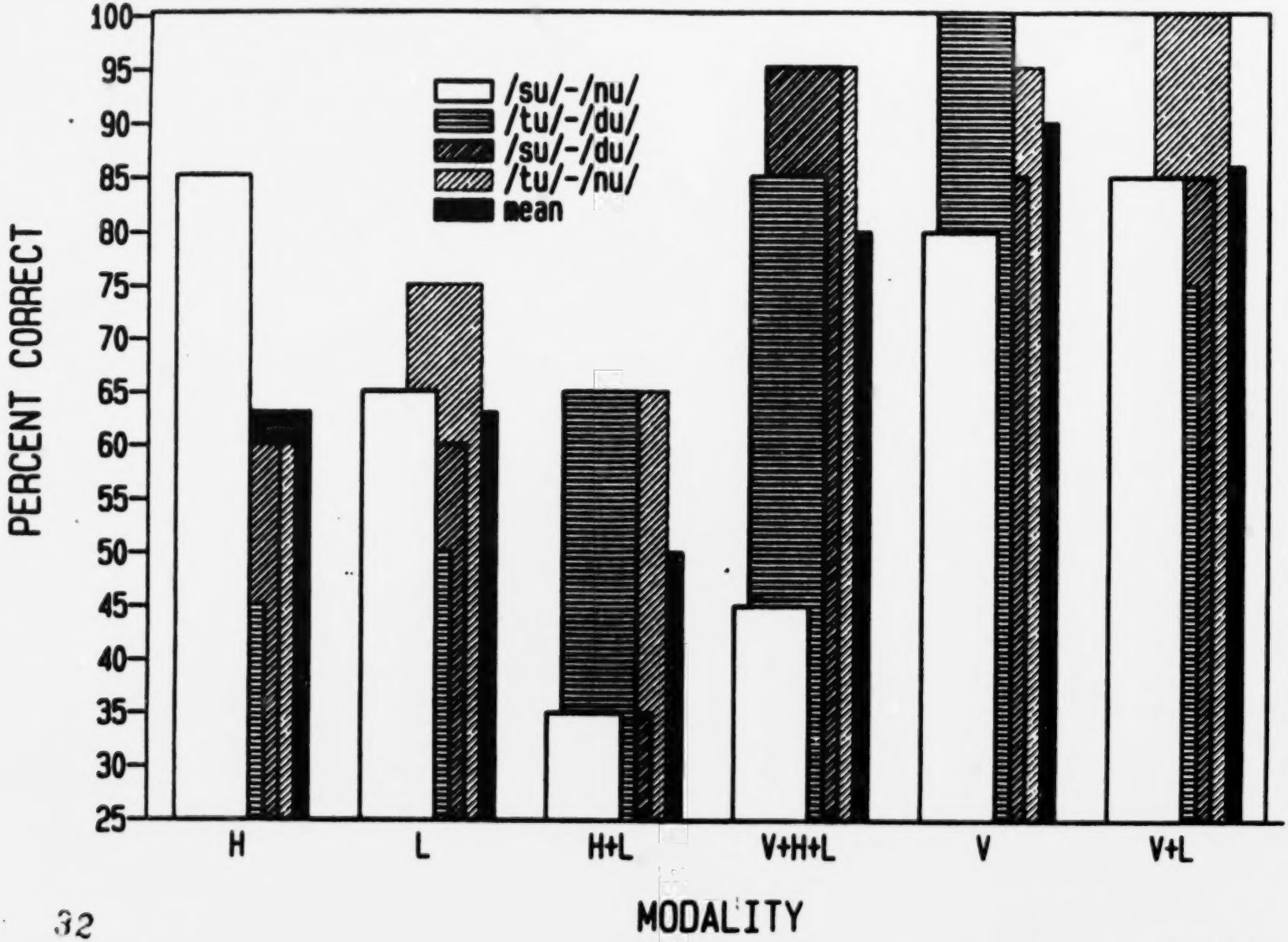

2-CHOICE DISCRIMINATION (SUBJECT 1)
PERCENT CORRECT
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
/su/-/nu/
/tu/-/du/
/su/-/du/
/tu/-/nu/
mean
H
L
H+L
V+H+L
V
V+L
MODALITY

FIGURE 2a

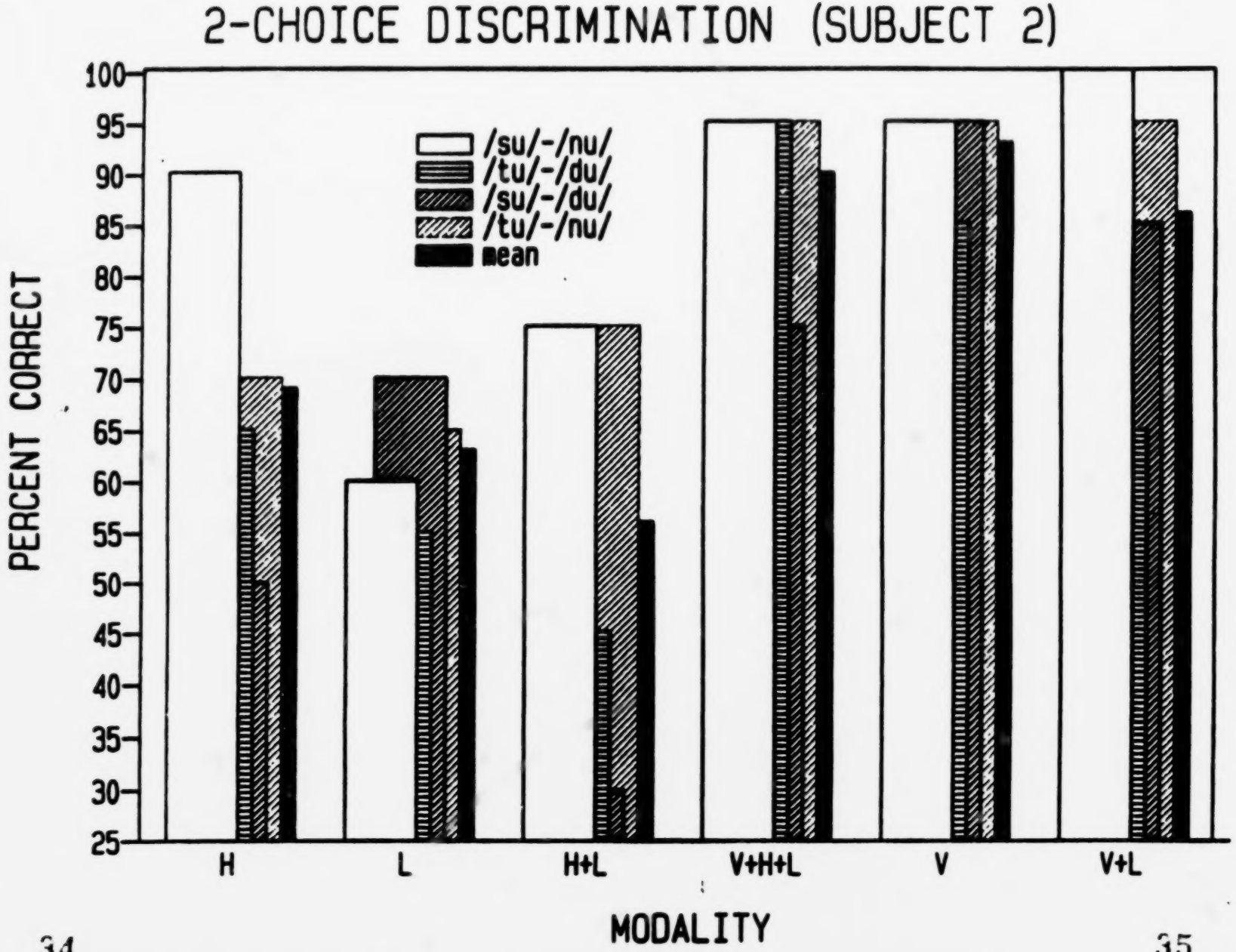

2-CHOICE DISCRIMINATION (SUBJECT 2)
PERCENT CORRECT
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
/su/-/nu/
/tu/-/du/
/su/-/du/
/tu/-/nu/
mean
H
L
H+L
V+H+L
V
V+L
MODALITY

FIGURE 2b

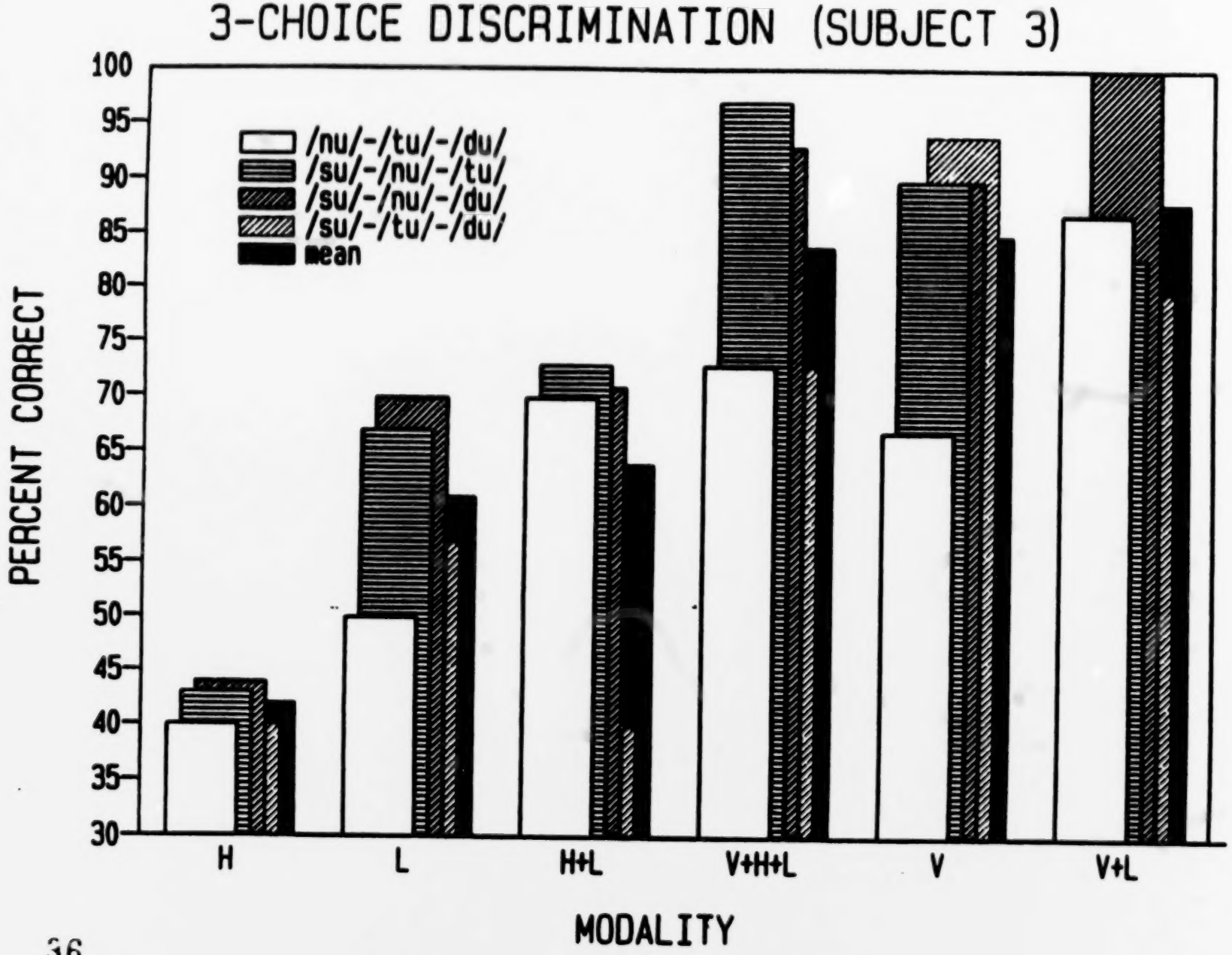

3-CHOICE DISCRIMINATION (SUBJECT 3)
PERCENT CORRECT
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
/nu/-/tu/-/du/
/su/-/nu/-/tu/
/su/-/nu/-/du/
/su/-/tu/-/du/
mean
H
L
H+L
V+H+L
V
V+L
MODALITY

FIGURE 3a

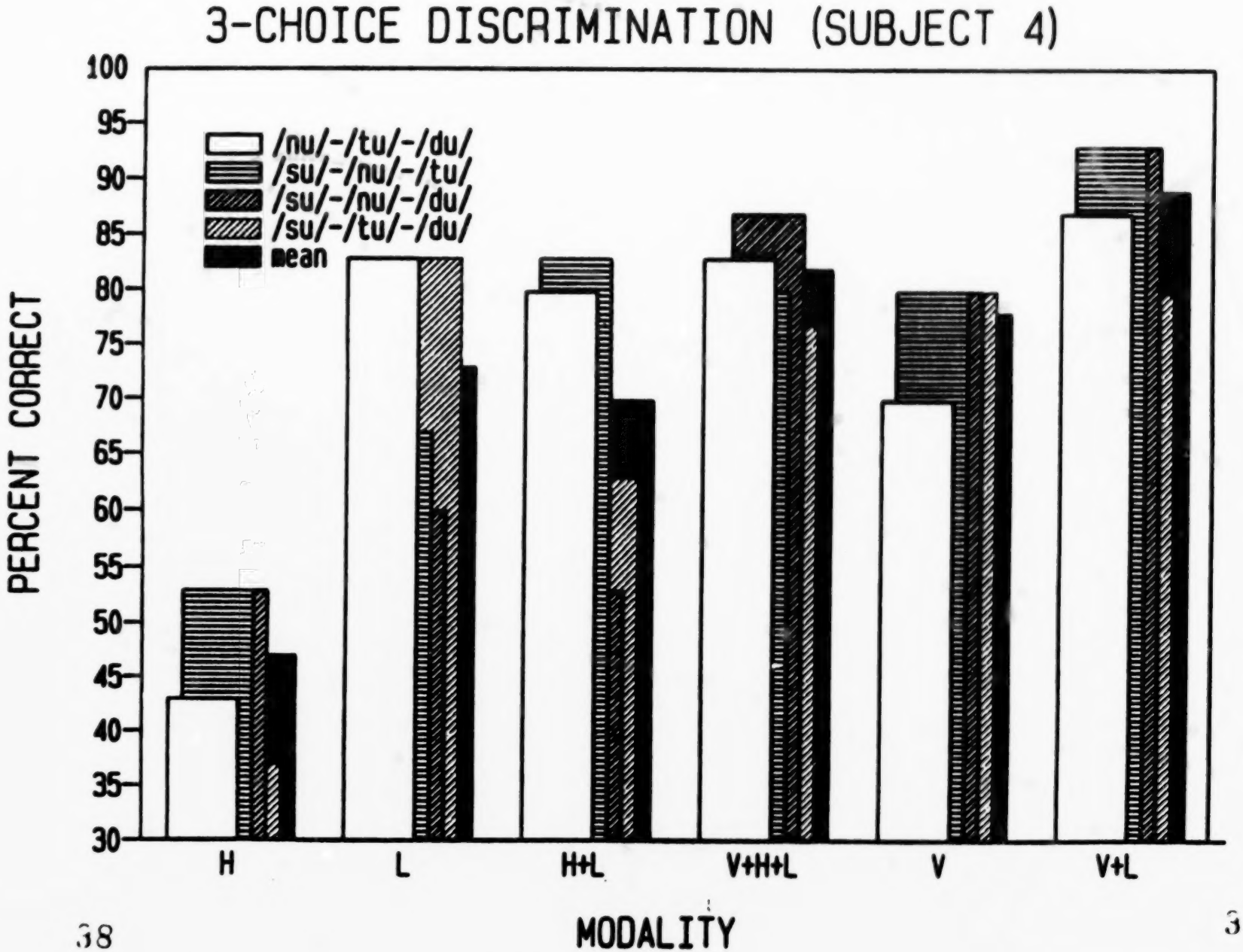

3-CHOICE DISCRIMINATION (SUBJECT 4)
PERCENT CORRECT
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
/nu/-/tu/-/du/
/su/-/nu/-/tu/
/su/-/nu/-/du/
/su/-/tu/-/du/
mean
H
L
H+L
V+H+L
V
V+L
MODALITY

FIGURE 3b

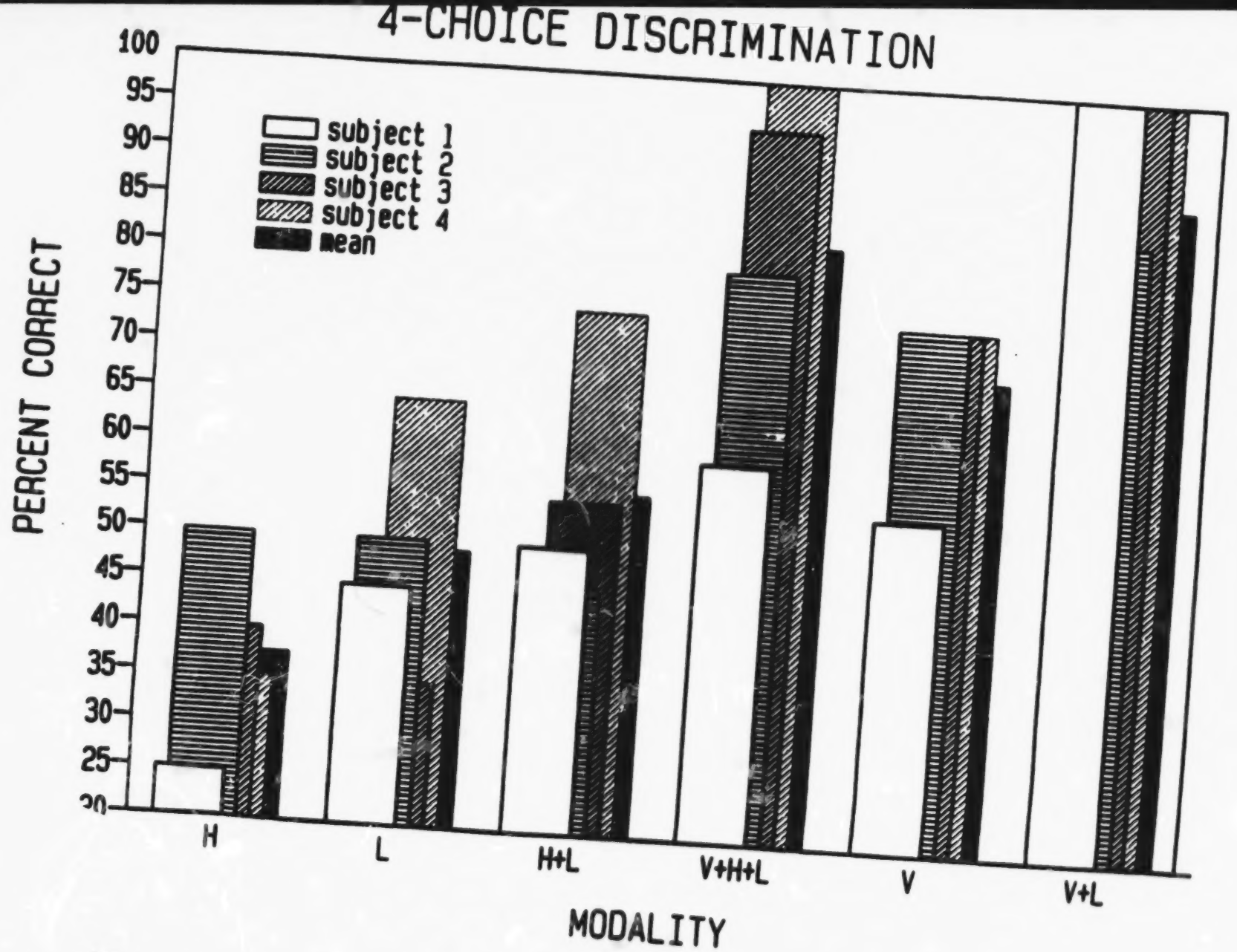

4-CHOICE DISCRIMINATION
PERCENT CORRECT
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
subject 1
subject 2
subject 3
subject 4
mean
H
L
H+L
V+H+L
V
V+L
MODALITY

FIGURE 4